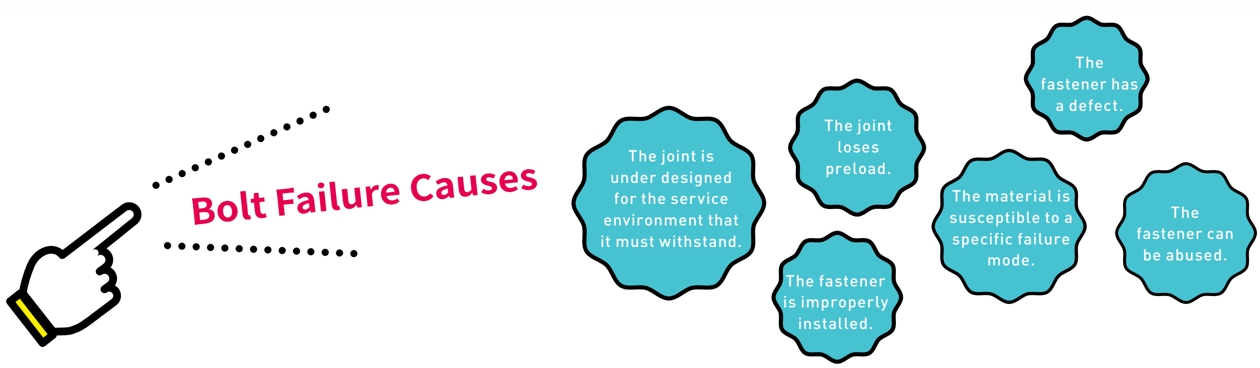
Dr. Fastener

Bolt Failure and Prevention

1 How do bolts fail?

A: To answer this, you must first understand that the bolt (or threaded fastener) is not a stand-alone item, but rather a part of a much more complicated system, which I will call the "Bolted (or Fastened) Joint". The Bolted Joint as a system is comprised of multiple variables which include the fastener components (bolt, nut, washers, etc.), the clamped materials, the applied loads, and the surrounding environmental conditions. When an engineer is designing the joint, they must take all these factors into consideration to ensure that the joint is robust and will not fail. If they get something wrong though, then the fastener components or the clamped materials can fail resulting in joint failure and potentially a failure of the larger system for which the joint is a part.

So, how do joints fail? We can **categorize failures into six different possible causes.**



1. **The joint is under designed for the service environment that it must withstand.** A couple of simple examples of this would be when a low strength bolt is used instead of a high strength bolt or a zinc plated steel part is used when stainless steel is needed. Common fastener failures resulting from this cause are overload and corrosion.

2. **The joint loses preload.** There are multiple reasons why a joint might lose preload, but more common reasons include relaxation from "soft joint" conditions and fastener embedment. When a joint loses preload, it becomes vulnerable to self-loosening or progressive failures like fatigue.

3. **The fastener is improperly installed.** In this case a fastener may be either "over" or "under" tightened. Over tightened fasteners usually fail by overload during installation, although embrittlement failures may be triggered by over installation. Under tightening possibly leaves a joint without sufficient preload and makes it vulnerable to fatigue or shear overload.

4. **The material is susceptible to a specific failure mode.** Examples of this might be materials that undergo creep and stress rupture behavior when exposed to elevated temperatures for long periods of time or fasteners that are susceptible to hydrogen embrittlement.

5. **The fastener has a defect.** Of course, defects are not limited to the bolt or fastener components but could be any part or component of the system. In the context of bolt or fastener failure, manufacturing and workmanship defects of the fastener components can contribute to failure. Common fastener defects that lead to bolt failures include thread laps, cracks, bursts, folds, and "unclean" raw material.

6. **The fastener can be abused.** This is not common, but should the system be abused by improper usage or maintenance it can lead to an overload or progressive failure like fatigue.

2 Is one of these causes more common than the others?

A: I am not aware of any studies or data that have explored this question in detail. In my past life, when I worked for a fastener manufacturer, I became conditioned to believe that most bolt (fastener) failures were the result of some sort of manufacturing defect. However, this is simply not true. In fact, I came across a statistic fifteen years ago that emphasizes this fact. It states that ninety-five percent (95%) of all fastener failures are due to poor selection or improper installation. If this is accurate, and I believe that it is, it means that **95% of failures can be attributed to lack of proper knowledge or execution of a robust bolted joint.**

3 What is an overload failure?

A: Simply stated, **an overload condition is where the applied stress on the fastener component is greater than it can handle.** Fasteners are commonly overloaded in tension, shear, and torsion. When the bolt is installed and tension is generated, the bolt will begin to stretch. Initially the relationship between elongation (stretch) and generated tension is linear. We say that the bolt is behaving elastically in this region. It cannot continue behaving this way indefinitely and eventually will reach its Elastic Limit. Once the bolt exceeds the Elastic Limit it will begin to exhibit permanent plastic deformation. If the Elastic Limit is greatly exceeded the bolt may reach its Ultimate Strength and fracture. This is tension overload. When loads perpendicular to the bolt's axis exist and are extreme the bolts may be "cut" into two. This is shear overload. When the installation torque is very high, parts may overload and fracture in torsion.

Overload failures can be a mixed blessing. If overload occurs during installation the effect of the failure is likely to be minimal, either requiring a replacement of the broken fastener or scrapping of the product. Obviously, such actions have negative cost implications but at this stage they are unlikely to be very high. The unfortunate side of overload failures, however, emerges when they fail in-service. Overload normally occurs when unexpected stresses are acting on the system. Examples of this are when the joint absorbs an impact or collision, joints unexpectedly must share loads from surrounding joints due to a progressive failure of another component nearby, or an extreme and unexpected natural event like an earthquake or tornadoes on the system. In these cases, the joint may fail rapidly and without warning. In the worst case, these overload failures result in fatalities and excessive property damage.

4 What is fatigue failure?

A: According to the ASM handbook, "Fatigue is the progressive, localized, and permanent structural change that occurs in a material subjected to repeated or fluctuating strains at nominal stresses that have maximum value less than (and often much less than) the static yield strength of the material." Unpacking that a little, it means this is a failure that happens over a period of time, often a very long period when parts that are vulnerable to fatigue are exposed to ongoing dynamic loading. **The fatigue failure mechanism consists of three stages; 1. Crack Initiation, 2. Propagation, and 3. Fast Failure.**

For fatigue failure to occur, a crack must be initiated. This usually happens at the site of a stress riser or small surface defect like a crack or thread lap. Once a crack initiates it will propagate with each load cycle- it will progress forward when the load is on and stop when the load is off. It continues to do this until the crack has progressed far enough that the remaining undamaged material is no longer able to support the load and the part will fail quickly in overload.

5 Can anything be done to prevent fatigue failure?

A: There are many things that can be done to fasteners to help reduce the risk of fatigue. The absolute best way to **prevent bolt fatigue is to properly design the joint and make sure that the applied preload is sufficiently greater than the sum of all the service loads.** However, additional manufacturing actions such as producing the part with high degrees of workmanship, rolling threads after heat treatment, rolling the filet radius after heat treatment, increasing radii, utilizing UNJ or MJ threads, and smoothing the thread runout transition are all means of reducing fatigue risk.

6 How do I prevent generating so much tension that the bolt breaks in overload?

A: The simple answer is to **understand the torque tension relation and execute installation properly.** There is a relationship between torque and tension, given by the equation T=kdP where T is the torque, d is the fastener diameter, P is the preload (or tension), and K is a constant called the Friction Factor. The Friction Factor is a function of all the frictional variables in the joint. Although some books reference values for K, the reality is that it will be different for each situation, so that the only way to have an accurate understanding of the actual relationship is to experimentally determine the K value.

If the torque tension relationship is accurately understood, then an installation process can be developed to consistently and accurately use a tightening torque value to achieve the desired preload. This is not necessarily hard but does take intentionality.

7 Do rusting parts pose a problem?

A: In small degrees, probably not, but **parts that are fully engaged and corroding are a big risk.** The part that is corroding is a little like a tooth with a progressing cavity. Once there is enough decay, the mechanical integrity of the part is compromised, and it will become vulnerable to a failure mode like fatigue or overload. Prevention of this problem is to employ an effective plating or coating, or when the environment is very severe to use a material better suited to the severity, such as stainless steel or a nickel alloy.

8 What is hydrogen embrittlement?

A: When a part has failed by hydrogen embrittlement it is often labeled as the root cause. This is incorrect. Hydrogen Embrittlement is only a failure mechanism. **The root cause of hydrogen embrittlement will always be material susceptibility.** Hydrogen embrittlement is a permanent loss of ductility in a metal or alloy caused by hydrogen in combination with stress, either externally applied or internal residual stress. Unpacking that a little, a material that is susceptible when provided a source of atomic hydrogen and tensile loaded above a critical value can have the hydrogen embrittle the grain boundaries in a vulnerable area of the part resulting in part fracture. Hydrogen embrittlement takes two forms, Internal Hydrogen Embrittlement (IHE) where the hydrogen source is introduced during manufacture, usually an electroplating process and Environmental Hydrogen Embrittlement (EHE) where the hydrogen source is introduced during service, usually by an active corrosion cell.

9 Is Hydrogen Embrittlement preventable?

A: Yes, but it takes understanding and deliberate execution to prevent the problem. First, it is important to distinguish between high risk and standard risk situations. **Any part that has a hardness above Rockwell 39 is automatically considered a susceptible material** and should be treated very carefully. High risk parts must be identified, and they should be properly baked for a sufficient length of time, undergo sustained load testing, and be processed with a plating process that has excellent process controls in-place.

Wrap-up

The questions addressed here provide a good basic overview of this topic, however, they just scratch the surface. Manufacturers and suppliers should have staff that are educated and knowledgeable about these failure mechanisms and how they may successfully lower the risk or prevent them from occurring entirely. ■

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